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Effect of renewable energy sources integration on the optimal coordination of directional over-current relays in distribution system

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Article Info	ABSTRACT
	The demand for power electricity is growing fast and one of the main tasks for power engineers is to generate electricity from renewable energy sources (RES). Nevertheless, problems arise when the new generation is integrated in the power distribution network. Under this condition, the main purpose in this paper, an investigation of the effect of RES integration on the optimal coordination of directional over-current relays in distribution system, a dual simplex optimization algorithm has been presented to determine the coordination of directional over-current relays (DOCRs). The system used to check the efficiency of the optimization algorithm which is IEEE 33-bus models. The analysis is performed in MATLAB software environment.

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1. INTRODUCTION

The worldwide demand for electricity continues to grow even as energy conservation measures and advances in power conversion efficiency reduce the consumption of individual loads. To feed the energy appetite of the world, renewable energy technologies are becoming feasible and offer alternative generation options that enable consideration of the impact on the environment and other social and economic factors [1]. The integration of renewable energy sources (RES) to the distribution network has numerous advantages. However, some problems in the coordination of protection devices will occur, due to changes in value and direction of power flow (under normal operation) and short-circuit current levels in different points (under fault conditions). The impact of RES on protective coordination depends on size, location and technology type of RESs. Therefore several ideas have been introduced as possible solutions to overcome the over-current (O/C) relay coordination problem in systems with DG [2].

The main objective of this study is to determine the optimal coordination of DOCRs in distribution system with renewable energy sources. The specific objective is to investigate the effect on fault current when installing RES in radial system and determine the new setting of the DOORs. Diverse methods have been reviewed by researchers in the past for optimal coordination of DOCRs, with distribution generation insertion in distribution system and FACTS diverse [3]. The authors in [4, 5] investigate the impacts on fault current when installing distributed generation on a radial system as well as the effect of the TCSC on the inverse definite minimum time (IDMT) directional over-current relay in distribution system.

In this paper, the problem of determining the optimum values of TDS of DOCRs had been formulating. The dual simplex optimization method with proposed algorithm is used to determine optimum values of TDS. The case studies with a 33-bus system with 32 DOCRs and 2 RES are presented to illustrate the proposed method. Based on the coordination results obtained in this research, the proposed dual simplex optimization algorithm can be used to calculate the settings of the directional over current relays in a distribution network with distributed generation. The proposed algorithm has shown to have the ability to maintain selectivity between the primary relays and backup relays.

2.   DISTRIBUTION SYSTEM DESCRIPTION

Renewable energy sources in power systems is one of attractive phenomena in power industry and it is no dispatch energy. With the presence of DGR units in distribution systems, its function would generally be changed and it would variously be affected by these units. One of the most important effects of these units is on distribution systems protection. Since the number of DGR units not only can be varied but also has a great deal of wide spread, distribution systems protective devices manner is completely changed with the presence of distributed generation.

RES units are electrical energy sources which are connected to distribution systems and in comparison with the large scale power stations, have a lower generation capacity and also have a lower starting cost. There are some cases in which the use of RES should be paid attention such as: economical problems in power stations developing, high efficiency of these sources, decreasing of environmental pollution, increasing of power quality, decreasing of loss in distribution systems, improvement of voltage profile and so one [6]. The majority distributed generators (DGs) are defined as renewable energy sources apply to the notion of generating power using a set of small sized generators that produces power at low voltage levels and usually uses alternative fuel. Distributed generators resources have been categorized as:

− Micro (-1 W<5 kW),
− Small (5 kW<5 MW),
− Medium (5 MW<50 MW),
− Large (50 MW<300 MW).

The RESs are mainly designed to be connected directly to the distribution network near load centers. There are several types of DGRs in the market. Some are conventional such as the diesel generators and some are new technologies such as the micro-turbines. The major DGR alternatives are described briefly in the reference [7].

3.   OPTIMAL COORDINATION OF DIRECTIONAL OVER-CURRENT RELAYS IN DISTRIBUTION SYSTEM

The current/time tripping characteristics of IDMT (inverse definite minimum time) relays may need to be varied according to the tripping time required and the characteristics of other protection devices used in the network. For these purposes, IEC 60255-3 defines a number of standard characteristics to find the over-current relays operating times which is defined by (5) and are indicated in Table 1. Typically, the inverse time over-current relay (OCR) consists of two elements, an instantaneous unit, and a time dependent unit. The time dependent unit has two values to be set, the Pickup current value (IP), and the time dial setting (TDS). The pickup value is the minimum current value for which the relay operates and the time dial setting defines the operating time (T) of the device for each current value. Normally, the characteristics of the directional over-current relay are given as a curve of (T) versus (M), where M (multiple of pickup current) is the ratio of the relay current, (I), to the pickup current value, (IP) [8, 9].

$$T = TDS \times \frac{\alpha}{M^{\beta} - 1} \quad and, \quad M = \frac{I}{I_P} \tag{1}$$

where, α and β are constants depending on the type of selected characteristics.

Table 1. Different type of IDMT characteristics cures

Relays characteristic	α	β
Standard inverse (SI)	0.14	0.02
Very inverse (VI)	13.5	1
Extremely inverse (EI)	80	2
Long time inverse (LTI)	120	1

3.1. Backup-primary constraint

Each relay's pickup current has minimum and maximum values as shown in (3). These values are chosen to be 1.2 and 2 times the maximum load current which is seen by each relay in a normal operation. Similarly, the time delay setting has minimum and maximum limits based on the relay's current-time characteristic. The minimum and maximum TDS are assumed to be 0.05 and 1.2 respectively in all over studies [10].

$$TDS_i^{min} \leq TDS_i \leq TDS_i^{max} \tag{2}$$

$$I_{Pi}^{min} \leq I_{Pi} \leq I_{Pi}^{max} \tag{3}$$

The minimum pickup current setting of the relay (I_{Pi}^{min}) is the maximum value between the minimum available current setting and the maximum load current max ($I_{load}i^{max}, I_{Pi}^{min}$). In similar, the maximum pickup current setting (I_{Pi}^{max}) is chosen as the minimum value between the maximum available current setting of the relay and the minimum measured fault current max ($I_{Fault}i^{min}, I_{Pi}^{max}$) [11]. In order to coordinate two over-current relays, one as main (primary) relay (i) and the other as backup relay (j), the difference between the operating time of backup relay and main relay should be more than the CTI(Coordination Time Interval). So the constraints for coordination of over-current relays i and j will be in the form of inequality (4) [12]:

$$T_j^K - T_i^K \geq CTI \tag{4}$$

T_j^K and T_i^K: are respectively the operation time of backup and primary relay for a short circuit in k. CTI is the time interval for coordination of primary and backup relay and it can take a value between 0.2 and 0.5 seconds, it depends on the type of relays, generally taken as 0.3 sec [13. 14].

4. APPLICATION OF DUAL SIMPLEX METHOD

Linear programming is one of the various techniques of optimization. It refers to modeling and solving a problem mathematically that involves the economic allocation of limited resources by choosing a particular course of action among various alternatives to achieve the desired accuracy [15]. Dual simplex method is a variant of regular simplex method, developed by Lemke, to solve a LPP. It starts from infeasible solution to the primal. The method works in an iterative manner such that it forces the solution to become feasible as well as optimal at some stage [16].

4.1. Problem formulation

The total time objective function in (5), for N primary relay is minimized, subject to various constraints (2) and (3). These constraints are relay setting constraints and backup-primary relay constraints:

$$\min \sum_{i=1}^{N} T_{i,K} \tag{5}$$

where N is the number of relays, $T_{i,k}$ is the operating time of the relay R_i, for fault in zone k.

4.2. Relay characteristics

In this paper the DOCR's are assumed to have normal IDMT characteristic as comply with the IEC60255-3 standard. The characteristics of the DOCR are given as a curve of T versus M, where, i.e.

$$M = \frac{I}{I_P} \tag{6}$$

where M is a multiple of the pickup current. I is the relay current (overload or fault current) and I_P is the pickup current. From (1) one can see that the relation between the operating time T and the multiple pickup current M, is nonlinear. Since the multiple pickup current of the relays can be predetermined, so for a fixed M, (1) becomes linear as follows:

$$t = a * TDS \tag{7}$$

where;

$$a = \frac{0.14}{\left(\frac{I_f}{I_p}\right)^{0.02} - 1} \tag{8}$$

by substitution from (8) in (1), the objective function becomes;

$$\min \sum_{i=1}^{N} a_i \times TDS_i \tag{9}$$

Formula (9) is optimized using LP-dual simplex method [16] subject to the condition that the operation of the backup relays remains properly coordinated.

5. CASE STUDIES

In this paper IEEE 33-bus radial distribution test feeder is considered for optimum relay coordination between primary and backup directional over-current relays in presence of two emplacements of renewable energy sources. The operating voltage is 12.66 kV. Directional over-current relays are used in the system to protect the feeder in case of three phase faults. The single line diagram of the IEEE 33-bus system is presented in Figure 1 [17, 18]. The model is simulated in MATLAB software without and with renewable energy sources to calculate the optimal setting of DOCRs using dual simplex method under system changes. The program is implemented for two emplacements of renewable energy sources. Three phase faults are generated on each bus.
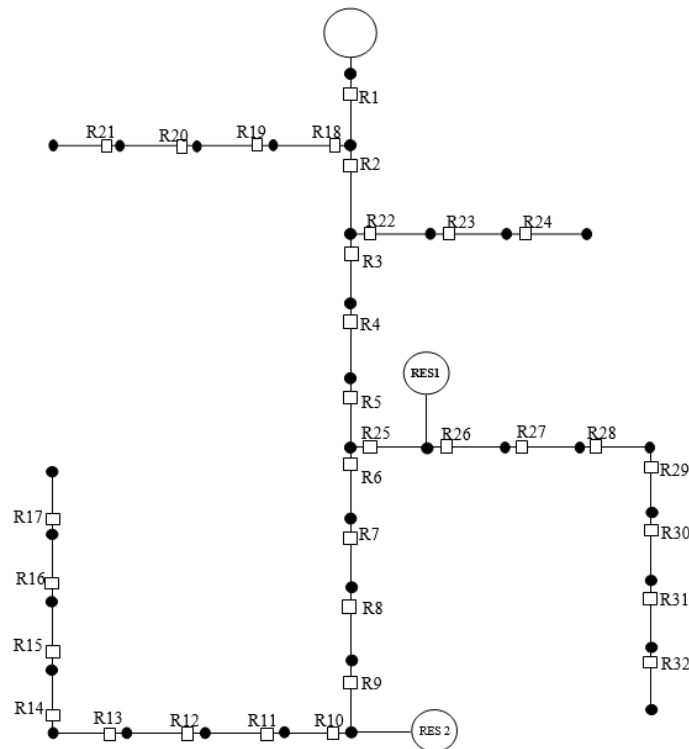

Figure 1. Power distribution system of the IEEE 33-bus system under study

6. RESULTS AND DISCUSSION

The main contributions of this paper are using the optimization technique to find optimal relay settings (TDSs), solve the linear problem of DOCRs with the system changed topology. Installing RESs leads to placing impedance in parallel with a part of network; therefore the impedance seen at fault location is reduced, the presence of RESs will change the normal power flow as well as the fault current, which are not restricted to the connected bus. The relay coordination problem is solved as optimization problem and optimised relay settings are obtained with standard time inverse DOCRs relays.

In order to minimize the objective function in (5), the best global positions (TDS) are calculated using dual simplex algorithm. Throughout the calculations, the pick-up currents are kept constant (Ip=1). The IDMT standard inverse (SI) curve is assumed for all calculations. Table 2 shows the optimized TDS values for different relays involved in coordination for the network before connecting the RESs. These values were obtained during coordination process.

Table 2. Optimal TDSs with RESs

Relays	TDSs for (Ip=1)	
	Without RESs	With RESs
R_1	0.675663	0.670406
R_2	0.453419	0.448362
R_3	0.323825	0.318034
R_4	0.318309	0.309247
R_5	0.304144	0.281219
R_6	0.274135	0.255640
R_7	0.143893	0.123048
R_8	0.183217	0.153524
R_9	0.154617	0.161653
R_10	0.163167	0.113031
R_11	0.096253	0.089085
R_12	0.136368	0.136354
R_13	0.157917	0.156935
R_14	0.071023	0.070195
R_15	0.062127	0.061512
R_16	0.166054	0.155771
R_17	0.478715	0.439360
R_18	0.596469	0.424051
R_19	0.541619	0.340930
R_20	0.260460	0.229842
R_21	0.750357	0.598877
R_22	0.238622	0.254837
R_23	0.179890	0.216386
R_24	0.426788	0.454004
R_25	0.372167	0.137460
R_26	0.555465	0.255056
R_27	0.261937	0.199023
R_28	0.163131	0.203094
R_29	0.148502	0.220710
R_30	0.223147	0.321115
R_31	0.186814	0.147084
R_32	0.615710	0.234190

Table 2 shows the values of TDSs calculated to be used in the adaptive coordination after connecting RESs at bus 26 and at bus 10 respectively. Comparing the values of TDSs got in the coordination before connecting the RESs and the values of TDSs got after connecting the RESs using adaptive protection scheme, it was seen that if the operating time of the relay is reduced due to increase in fault current seen by that relay, its TDSs value need to be increased in order to maintain the operating time as it was before connecting the RESs. Similarly, if the operating time of the relay is increased due to decrease in fault current which seen by that relay, its TDSs value need to be decreased in order to maintain the operating time as it was before connecting the RESs. In general, it is observed that there is remarkable improvement in their TDS of relays in presence of RESs in the distribution system. The increase in the fault current decreased the operating time for the relays located downstream from the faulted bus and increase the operating time for the relays between the substation and RESs.

7.   CONCLUSION

In this paper the authors proposed the dual simplex method to solve the problem of coordination of DOCR's relays in presence of renewable energy sources in the distribution system. The results prominently show effectiveness of linear programming optimization for designing optimum protection scheme for radial distribution systems in presence of renewable energy sources using DOCRs. Furthermore, we propose, in the future work, the application optimization techniques to find the optimal TDS and Ip for DOCRs in distribution system in the presence of renewable energy sources. Based on the coordination results obtained in this research, the proposed dual simplex optimization algorithm can be used to calculate the settings of the directional overcurrent relays in a distribution network with distributed generation.

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